

ROCKS, RESOLUTION, AND THE RECORD AT THE TERRESTRIAL K/T BOUNDARY,
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Reconstructions of mass extinction events are based upon faunal patterns, themselves reconstructed from numerical and diversity data ultimately derived from rocks. It follows that geological complexity must not be subsumed in the desire to establish patterns. This is exemplified at the terrestrial Cretaceous-Tertiary (K/T) boundary in eastern Montana and western North Dakota, where there are represented all of the major indicators of the terrestrial K/T transition: dinosaurian and non-dinosaurian vertebrate faunas, pollen, a megaf flora, iridium, and "shocked" quartz. It is the patterns of these indicators that shape ideas about the terrestrial K/T transition. The question is, how are the patterns to be interpreted?

In eastern Montana and western North Dakota, the K/T transition is represented lithostratigraphically by the Cretaceous Hell Creek Formation, and the Tertiary Tullock (= Fort Union in North Dakota) Formation. Both of these are the result of aggrading, meandering, fluvial systems, a fact that has important consequences for interpretations of fossils they contain. Direct consequences of the fluvial depositional environment are:

- 1) facies are lenticular, interfingering, and laterally discontinuous. No single bed constructed by the fluvial system can be expected to have great temporal or spatial continuity;
- 2) the occurrence of fossils in the Hell Creek and Tullock formations is facies-dependent, that is, the final distribution of vertebrate fossils in space and time is primarily a function of the distribution of components of the fluvial system in space and time, rather than a function of the ecology of the animals themselves; and
- 3) the K/T sequence in eastern Montana and western North Dakota is incomplete, as indicated by repetitive erosional contacts and soil successions.

The significance for faunal patterns of each of the above points is discussed below.

(1) *Lenticular facies.* Lenticular facies are a direct consequence of the aggrading channel system that deposited the sediments. The lenticularity largely arises from channel geometry, channel migration, and associated erosion and redeposition. In eastern Montana and western North Dakota, the scale of discontinuities between the badlands outcrops is larger than the scale of the elements that composed the ancient fluvial system. The result is that, with some exceptions, bed-by-bed correlations between discontinuous outcrops are probably illusory.

This is notoriously true of coals. No feature of the sedimentary regime outlined above could produce a single coal (let alone two coals) covering all of eastern Montana and western North Dakota. Observed lateral discontinuities (Fastovsky, 1987) provide every reason to doubt the time stratigraphic significance of Hell Creek coals. Local coals that developed in the region during the latest Cretaceous belie the illusion that a single coal represents the K/T boundary. Evolutionary inferences drawn from the stratigraphic relationships of faunas to a "Z-coal" (Sloan et al., 1986; Rigby et al., 1987) indicate that a lithostratigraphic indicator (the coal) and a chronostratigraphic datum (the K/T boundary) were confused.

(2) *Facies-dependent preservation.* The distribution of vertebrate fossils in a fluvial system, like the geometry of facies that comprise the system, is a function of fluvial processes. Because vertebrate materials are largely allochthonous intraclasts in fluvial systems, ecology does not constrain preservation. For example, channel facies appear rich in vertebrate fossils *not* because dinosaurs lived in river channels, but rather because when channels erode floodplains, they concentrate coarse material (including vertebrate fragments) at their bases as bed load. In the Hell Creek, as 40% of the total preserved vertebrate fossils are found in channel (i.e., thalweg and point bar) facies. This means that equivalent thicknesses of fluvial deposits are not comparable in terms of number and/or diversity, unless identical facies are being compared; distance from the K/T boundary is uninterpretable unless the facies through which that distance is measured is being identified.

(3) *Incompleteness*. The sedimentary incompleteness of the Hell Creek Formation has been reported elsewhere (Dingus, 1984; Fastovsky, 1987); the combination of erosion and hiatuses during times of soil formation ensure that not nearly all the time encompassed between any two given datums is actually represented by rock. How much time *is* represented? Dingus (1984) observed that the probability of identifying rocks from a selected 1000 year interval is 1 in 10, based upon Sadler's (1981) estimates for sedimentary completeness. Fastovsky (1987), using sedimentation rates measured in modern environments inferred to be similar to the ancient ones, estimated that only 600,000 years of sedimentation are represented by the full pile of Hell Creek sediment, said to encompass about 3 million years. In fact, the amount of time represented by the Hell Creek remains unknown, because although paleosols comprise 60% of the thickness of the Montana and North Dakota K/T boundary sections, rates of soil formation are probably not ascertainable (Fastovsky and McSweeney, 1987).

This has significant ramifications in the Hell Creek and Tullock Fms., where estimates of faunal number and/or diversity have been attempted based upon inferred sedimentation rates measured per unit thickness of formation (eg., Russell, 1982; Alvarez, 1983). The utility of such estimates is constrained by our ability to infer only *depositional* rates, and not the amount of time represented by *erosion* and *non-deposition*, which together account for far more time than is accounted for by deposition alone. Moreover, previous estimates of dinosaurian number and diversity do not take into account the fact that different facies formed at different rates. Channel fills formed orders of magnitude more rapidly than floodplains, based upon modern analogs (Bridge and Leeder, 1979). Averages of depositional rates have little meaning when rates of deposition among facies are so divergent.

The foregoing does not obviate the fact that reconstructions of evolutionary patterns of vertebrate faunas are possible in Hell Creek sediments, as long as an awareness of the realities of deposition and resolution in 65 million-year-old fluvial sediments is maintained. A project attempting to reconstruct vertebrate evolution in a reproducible manner in Hell Creek-type sediments must be based upon 1) a *reliable* scale of correlations, given the lenticular nature of the deposits, and 2) a recognition of the fact that disparate facies are not comparable in terms of either numbers of preserved vertebrates or depositional rates.

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